Developing a Network of Sedimentation Erosion Tables to Determine the Stability of a Hydrologically Altered Pacific Northwest Estuary Given Sea-Level Rise

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Abstract
Insufficient sedimentation and relative sea-level rise (eustatic sea level rise plus land subsidence) are contributing to coastal wetland loss. Additionally, the eustatic sea-level rise component of relative sea-level rise (RSLR) is expected to accelerate over the next 100 years. In order to sustain elevation, estuaries must accrete vertically at a rate that equals RSLR. In Padilla Bay, one of the largest contiguous sea grass meadows on the Pacific coast, water flow from the Skagit River has been altered such that the ability of the estuary to remain stable in the face of sea-level rise is uncertain. A recently developed field technique that uses sediment horizon markers in conjunction with a sedimentation-elevation table (SET), makes it possible to partition and measure vertical accretion and shallow subsidence. We installed a network of 18 SETs throughout Padilla Bay. We will compare mean accretion and subsidence rates with recent and future sea-level rise scenarios to determine the elevation deficit or surplus within the bay and determine whether areas of the bay are at risk due to increased rates of SLR.

Introduction
Given the value of the world's coastal ecosystem services and functions (Costanza *et al.* 1997), high population growth rate and development pressure in coastal areas and the projection that the rate of sea-level rise will increase 2- to 5-fold by 2100 (Watson *et al*. 1996), it is vital that we accurately estimate the potential for coastal wetland submergence and understand the processes driving surface elevation change.

Estuarine wetlands, sea-grass beds and mudflats exist in a dynamic equilibrium between processes that lead to their establishment and maintenance (mineral and organic matter accumulation) and processes that lead to deterioration (sediment compaction, organic matter decomposition, eustatic sea level rise, and deep subsidence). If coastal estuaries are to sustain elevation in the face of rising water levels, they must accrete vertically at a rate that equals relative sea level rise (eustatic sea level rise plus subsidence).

Padilla Bay contains more than 3,000 ha of sea grass (Webber 1987) consisting of *Zostera marina* (2/3 of stand) and *Zostera japonica* (1/3 of stand) (Thom and Hallum 1990). The Skagit River was once the major source of sediment to Padilla Bay, transported via the Swinomish channel. However, damming and levees along the river have reduced sediment load such that the channel is no longer a major source of nutrients of sediment to the bay (Bulthuis 1995).

While research on accretion and subsidence rates in coastal marshes along the east coast is extensive, less is known about estuarine systems of the Pacific Northwest. In general, these marshes seem better able to keep pace with small increases in eustatic sea level rise (Patrick and Delaune 1990). Thom (1992) reported a mean accretion rate of 3.6 mm/yr for coastal salt marshes in Washington and Oregon, a rate exceeding average sea-level rise, suggesting the ability of these marshes to keep up with present sea-level rise (1 to 2.5 mm/yr). However, because riverine sediment input to Padilla Bay has decreased, there is reason to believe that regions of the marsh are subsiding and that accretion is insufficient to sustain marsh elevation given predicted sea level rise scenarios (Figure 1). WDOE predicts a 46% decline in Padilla Bay tidal flats with a 50 cm rise in sea level (Park *et al*.1992). Our objectives are to: (1) Determine sediment accretion/subsidence rates and elevation deficits/surplus within Padilla Bay; (2) Project the long-term stability of estuary elevation given predicted eustatic sea level rise scenarios and; (3) Determine how ground cover type (mud flat, *Z. marina, Z. japonica*) regulates accretion rate.

Methods
Vertical accretion is measured as the accumulation of sediment over feldspar horizon markers which consist of 0.25 m^2 plots of feldspar clay spread onto the estuary surface to an approximate depth of 1 cm. Surface elevation change is measured using an SET developed for high precision measurements of surface elevation in wetlands (Boumans and Day 1993) (Figure 1). The SET is a portable leveling device that can be attached to a permanent benchmark steel pipe driven into the marsh to a depth of 3 to 6 meters. Nine pins located at the end of a leveled horizontal arm are lowered to the marsh surface to measure elevation change at four orientations for a total of 36 measurements. Shallow subsidence

Figure 1. Photo series: Driving the steel benchmark to the ‘point of refusal’; establishing feldspar plots; and measuring elevation change with a sediment erosion table (SET).

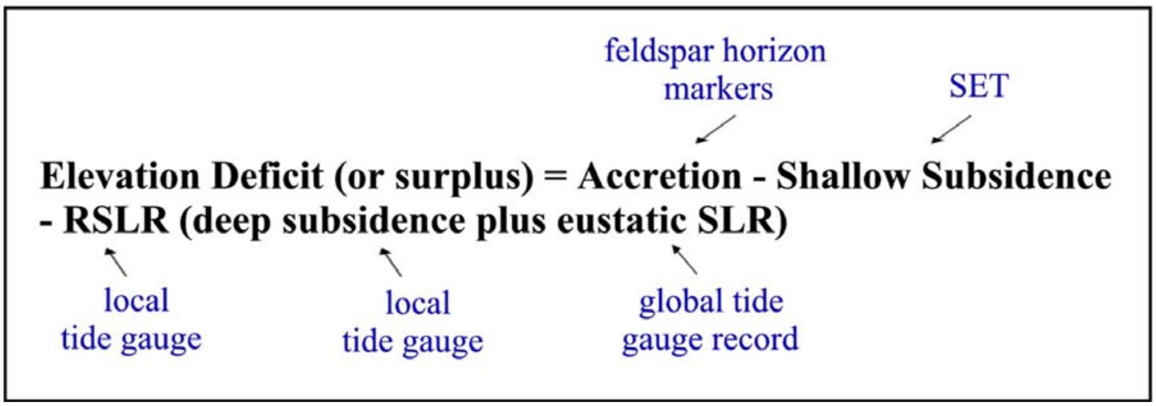

Figure 2. Calculation of estuarine elevation is made using data from SETs, feldspar horizon markers, and tide gauge data. Shallow subsidence is an important component for determining elevation change (and is often ignored when only tide gauge and accretion data are used in the calculation).

is calculated as: vertical accretion minus the change in elevation (Cahoon *et al*. 1995). Deep subsidence is calculated by subtracting eustatic SLR from RSLR. These measurements are used to calculate elevation deficit (or surplus) (Figure 2). We use projected sea level rise scenarios as defined by the Intergovernmental Panel on Climate Change (Church *et al.* 2001): “Current trends”, 0.15 cm/yr; and “Best estimate”, 48 cm by 2100. Local RSLR trends over 25 years were determined by NOAA to be 1.24 $^{+}$/- 0.2 mm/yr for nearby Friday Harbor.

We used a randomized block experimental design with blocks representing different sediment sources. We established a total of 18 SET sites in the bay during summer of 2002 (Figure 3) and collected elevation data in summer 2002 and in April 2003 and monitoring will continue until June 2004. Preliminary data shows that accretion over feldspar markers in occurring at many of the sites, while overall elevation change is negative at all sites suggesting shallow subsidence is occurring. We will use ANOVAR to determine if significant differences in rates of accretion, subsidence or elevation change exist among different areas of the bay. We will compare local RSLR and predicted eustatic SLR rates with accretion and subsidence rates to determine which areas of the bay are at risk for elevation loss due to increasing SLR rates.

As a second experiment, we cored randomly located feldspar horizon markers located within a single elevation (middle intertidal); in each of three ground cover types: bare mud flat; *Zostera marina*; and *Zostera japonica*. We found that cover type does affect accretion rate. There was no accretion and an unknown extent of erosion (feldspar marker washed away) in all mud flat plots while there was an average of 1.43 and 1.46 cm of accretion in *Z. japonica* and *Z. marina* plots respectively. There was no significant difference in accretion rates between accretion rates in these plots.

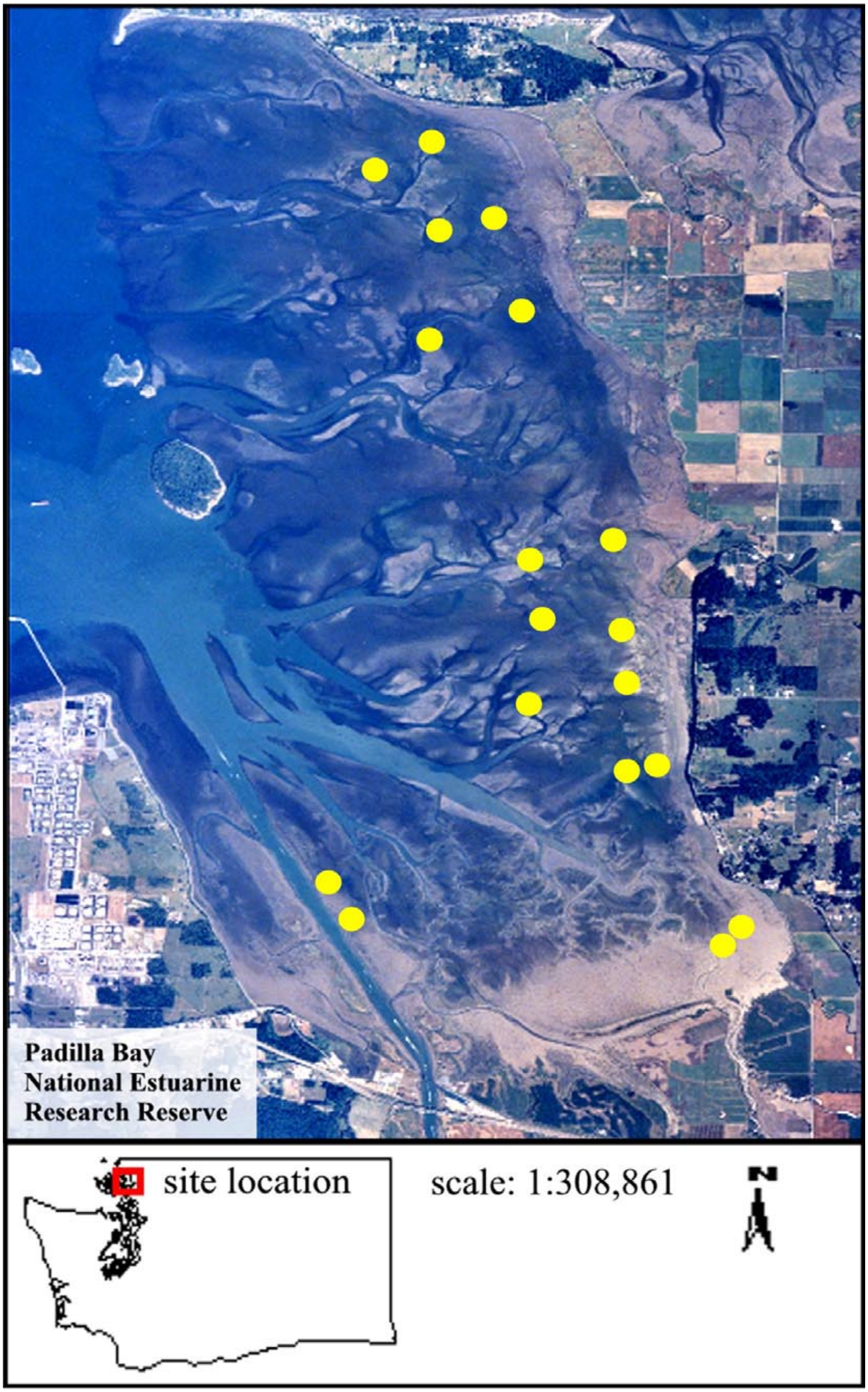

Figure 3. We installed a network of 18 Sediment Erosion Tables throughout Padilla Bay. Map courtesy of Padilla Bay National Estuarine Research Reserve.

This study will provide pertinent information on the sustainability of the entire Padilla Bay estuary that can be applied to management and restoration decisions. For instance, the US Army Corps of Engineers and Skagit County are currently undertaking the Skagit River Flood Damage Reduction Feasibility Study to find ways increase flood control. A proposed bypass project consists of a channel that would take floodwater from the Skagit River near Burlington and Mount Vernon to Padilla Bay via the Swinomish channel. The results of this research will provide baseline data useful for determining whether increased water flow is necessary to maintain sedimentation rates in Padilla Bay given sea-level rise.

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